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# Stock status of alewives and blueback herring returning to the Mactaquac Dam, Saint John River, N.B.

# État des stocks de gaspareaux et d'aloses d'été remontant au barrage Mactaquac sur la rivière Saint-Jean (N.-B.)

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## Abstract

Linear empirical stock-recruitment relations were found between the escapement of alewives *Alosa pseudoharengus* and blueback herring *A. aestivalis* to the Mactaquac Lake on the Saint John River, New Brunswick, in year *i* and the year-class abundance at age 3 returning to the fishway at the Mactaquac Dam. The slopes were low but statistically significant whereas the slopes were non-significant for returns in years *i*+4 and *i*+5 in all but one case. Spawning escapements of 500,000-1,000,000 alewives produced year-class sizes at age 3 of 500,000-2,000,000 fish while blueback herring escapements of 200,000-300,000 fish produced year-class sizes at age 3 of 100,000-2,500,000 fish. The variability in returns of both species was high for a given spawning escapement, thereby reducing the value of the stock-recruitment relations as a predictive tool. Outlier years were identified by a robust regression method. Outlier removal resulted in significant stock-recruitment relations in three of six cases. No significant correlations were found between several measures of stock abundance and water temperatures at several depths in the Emerald Basin on the Scotian Shelf. Declining mean ages, lengths, and weights for both alewives and blueback herring at first spawning (sexual maturation) was probably due to the effects of fishery exploitation. The proportion of alewives first spawning at ages 3 and 4 increased while the proportion at ages 5 and 6 decreased. The proportion of blueback herring that spawned first at age 3 increased slightly, remained essentially constant (with high variability) at age 4 and declined at ages 5 and 6. The proportion of previous-spawners decreased in response to exploitation for both species and may offer a useful way of assessing stock status.

## Résumé

Nous avons trouvé des relations stock-recrutement empiriques linéaires entre l'échappée de gaspareaux (Alosa pseudoharengus) et d'aloses d'été (A. aestivalis) durant l'année i au lac Mactaquac, sur la rivière Saint-Jean (Nouveau-Brunswick), et l'abondance des poissons de la classe d'âge de trois ans remontant à la passe migratoire du barrage Mactaquac. Les pentes de ces relations étaient faibles mais statistiquement significatives, alors que toutes les pentes sauf une étaient non significatives pour les remontes des années i+4 et i+5. Des échappées de 500 000 à 1 000 000 gaspareaux ont produit de 500 000 à 2 000 000 poissons de classe d'âge de trois ans, tandis que des échappées de 200 000 à 300 000 aloses d'été ont donné de 100 000 à 2 500 000 poissons de classe d'âge de trois ans. Pour une échappée donnée, la variabilité des remontes des deux espèces était élevée, ce qui réduit la valeur des relations stock-recrutement comme outil de prévision. Les années aberrantes ont été relevées grâce à une méthode de régression robuste. L'élimination de ces points aberrants a permis d'obtenir des relations stock-recrutement significatives dans trois cas sur six. Nous n'avons trouvé aucune corrélation significative entre diverses mesures de la taille des stocks et la température de l'eau à plusieurs profondeurs dans le bassin d'Émeraude, sur la plate-forme Scotian. La baisse des âges, longueurs et poids moyens du gaspareau et de l'alose d'été à la première fraye (maturation sexuelle) était sans doute attribuable aux effets de la pêche. Les proportions des gaspareaux frayant pour la première fois à l'âge de 3 et de 4 ans ont légèrement augmenté, tandis que les proportions de poissons frayant pour la première fois à l'âge de 5 et de 6 ans ont baissé. La proportion des aloses d'été frayant pour la première fois à 3 ans a légèrement augmenté, celle des poissons frayant pour la première fois à 4 ans est restée constante (avec une forte variabilité) et celles des poissons frayant pour la première fois à 5 et à 6 ans ont baissé. La proportion des poissons des deux espèces ayant déjà frayé a diminué en raison de leur exploitation et pourrait constituer une façon utile d'évaluer l'état des stocks.

## Introduction

Anadromous alewives (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*), jointly and commonly called gaspereau, river herring, or simply alewives, support an important commercial fishery (1950-2000 mean catch of 2,284 t) on the Saint John River, New Brunswick (Figures 1, 2). The commercial harvest of gaspereau from the Saint John River has fluctuated below the long-term mean since 1980. Since the commercial fishery at the dam began in 1974, the harvest of gaspereau from the Mactaquac Dam has composed an average of 20.7% (range 4.8-41.4%) of the total harvest from the river. Jessop (1986a, 1990a) has described relations between stock size and recruitment for alewife and blueback herring returning to the Mactaquac Dam, located about 148 km upstream of the mouth of the river. This assessment updates previous assessments of the stock status and reexamines the empirical stock-recruitment relations of alewives and blueback herring returning to the Mactaquac Dam. Jessop (1999, 2001) discusses the status of the stocks exploited by the commercial fisheries of the lower Saint John River.

### Stock and Fishery Characteristics

Maturing gaspereau may move into the lower Saint John River, e.g., Kennebecasis Bay, as early as January but the major upstream spawning migration begins, depending upon annual weather conditions, about late April, peaks in late May or early June, and is completed by early July. The run peaks progressively later with distance traveled upstream. Alewives enter the river first, followed by blueback herring 2-3 weeks later. Biological and tagging evidence for the existence of geographic subpopulations of alewives and blueback herring within each major tributary lake, including Mactaquac Lake, is presented by Messieh (1977), Jessop et al. (1983), Jessop (1990a), and Jessop (1994a).

Both species recruit to the spawning stock by platoon (i.e., only part of a year-class is recruited in a given year; Ricker 1975) over 3 or 4 years between ages 3 and 6, mostly at age 4 or 5. Annual returns are composed of varying numbers of both virgin recruits and previous spawners. All gaspereau returning to the Mactaquac Dam (completed in 1968) are either transported upstream by tank truck to the headpond for release or harvested (return equals escapement plus harvest). Downstream passage occurs through the hydroelectric turbines at the dam. The commercial harvest begun in 1974 at the dam removed those fish deemed to be surplus to required spawning escapements (Jessop 1990b). Most of the annual spawning escapement of alewives was passed to the headpond (Mactaquac Lake) before harvest began; blueback herring escapement occurred concurrently with the harvest. The patterns of alewife and blueback herring return to the Mactaquac Dam have been roughly similar, with two peaks of abundance (late 1970s and late 1980s), but the pattern of spawning escapements has differed due to various fishery management plans (Figure 3).

### Stock Management History

The program of active, adaptive fishery management (eg., Walters 1986) of the return of alewives and blueback herring to the Mactaquac Dam was abandoned in 1986 after five years of operation due to early termination of a proposed 10 year program to vary annual spawning escapements over as wide a range as possible (Jessop 1990b). A period followed of ad hoc annual management plans, a multi-year management plan (1991-1993), and a single year plan in 1994 in the absence of agreement for a multi-year management plan. A series of 3 year management plans has been implemented in recent years as a result of periodic negotiations with stakeholders within the SW New Brunswick Shad/Gaspereau Advisory Committee.

From 1974 to 1976, escapements of both species were held relatively constant at about 650,000 alewives and 150,000 blueback herring (Figure 3) while between 1977 and 1981, escapements were set (within operational limits) at 290,000 alewives and 250,000 blueback herring (Jessop 1990b). Between 1982 and 1986, spawning escapements were actively manipulated in a program of active management designed to establish the response to a wide range of spawning escapements (Jessop 1990b). Alewife spawning escapements varied between 179,000 fish and 1,130,000 fish while blueback herring escapements varied within a range of 43,000-269,000 fish. The

fishway was closed in 1986 to blueback herring by order of the Minister of Fisheries and Oceans, apparently in response to long-standing opposition by commercial gaspereau fishermen in the downriver area. A reduced spawning escapement of alewives was achieved prior to the cessation of gaspereau escapement trucking. Although the long-term plan for active management ceased in 1987, plans continued between 1987 and 1989 to achieve an alewife escapement peak (2,109,000 fish) and subsequent low (104,000 fish) as well as a blueback herring low of 43,000 fish. Multi-year target escapements of 500,000 alewife and 200,000 blueback herring were set between 1990 and 1994 but not necessarily achieved for various operational, and attained run-size, reasons. Since 1995, the spawner escapement targets, achieved by negotiated agreement with stakeholders, have been 800,000 alewife and 200,000 blueback herring. These escapements produce a stocking density of 91.4 alewife/ha, 22.9 blueback herring/ha and a combined total of 114.3 gaspereau/ha, assuming that the available habitat is limited to the Mactaquac Dam headpond (8,748 ha). Gaspereau passage to the upstream Beechwood Dam headpond is negligible because the fishway is typically not opened until mid-June when upstream-migrant Atlantic salmon first appear.

Since the start of the annual commercial harvest at the Mactaquac Dam in 1974, gaspereau stock management on the Saint John River has largely focused on the harvest process and the determination and achievement of annual escapement levels to Mactaquac Lake for spawning (see minutes of the annual meetings of the SW New Brunswick Shad/Gaspereau Advisory Committee). The focus on the Mactaquac gaspereau stock originates in: (1) the availability of information on the harvest and spawning escapement levels at the Mactaquac Dam, (2) the geographically limited and temporally incomplete biological data on the downstream fishery and the absence of effort data to associate with catch data until the implementation of a logbook system in the late 1980s (Jessop 1999), (3) a general opposition by commercial fishers to the harvest of gaspereau at the Mactaquac Dam prior to the implementation of negotiated escapement levels, (4) a belief by some fishers that the spawning escapement to Mactaquac Lake provides the "seedstock" for the entire river and that geographic substocks and homing to a natal area do not exist within the Saint John River (but see Jessop (1994a)), (5) a reluctance by fishery managers to either move upstream to spawn all gaspereau arriving at the dam, due to high trucking costs and exacerbation of the problem due to increasing future stock size, or to leave large numbers of fish in the vicinity of the fishway until they disperse naturally at the end of the spawning season due to evidence that fishway entrance by Atlantic salmon might be delayed (Jessop1990b). When the Mactaquac Dam fishway was closed to blueback herring in 1986, they remained in the vicinity of the fishway until early July. This prompted complaints from anglers of Atlantic salmon (*Salmo salar*) and Mactaquac Fish Culture Station staff that Atlantic salmon were being prevented from or delayed in entering the fishway. Also, prior to the start of the commercial fishery in 1974, limitations in the capacity and activity level of escapement trucking resulted in delays in passage until mid-July or later (Jessop 1990a).

## Methods

From 1968 through 1999, the numbers and age compositions of each species harvested and released upriver from the Mactaquac Dam were estimated annually, as described in Jessop (1990a). Briefly, the number of fish harvested at the dam was estimated by dividing the weight of the fish (to the nearest 4.5 kg, later 1 kg) in each truck loaded during the time interval between biological samples by a two-sample moving average of the mean sample weight per fish (to the nearest 0.1 g). Numbers of fish in the escapement were visually estimated as the fish crossed a sill into the hopper before loading into tank trucks for transport to the headpond. Samples of 50 fish were collected weekly throughout the run from the fish-lift between 1973 and 1977 and twice weekly in 1978. Between 1979 and 1994, 100 fish were taken twice weekly and, since 1995, three times weekly.

Empirical relations were calculated between escapement to Mactaquac Lake in year $i$ and the total return to the dam (virgin recruits plus previous spawners) in years $i$+4 and $i$+5 (most virgin fish recruit at age 4 or 5) and year-class size at age 3 for alewife and blueback herring. Year-class size at age 3, for fish spawned in year $i$, was calculated from the numbers of virgin fish at ages 3-6 adjusted

for an instantaneous natural mortality (M) of 0.2. (Jessop 1990a). Data, coded (÷1,000) prior to analysis, were used in ordinary least-squares (OLS) linear regression:

$$R = \alpha + \beta E_i + \varepsilon_i$$

where $R$ is total return (i.e., recruitment); $E$ is escapement in year $i$; $\alpha$ and $\beta$ are the slope and intercept of the regression, respectively; and $\varepsilon_i$ is a constant assumed to be normally and independently distributed with zero mean and constant variance. The null hypothesis is that $R$ does not increase linearly with $E$ over the observed range of $E$. Measurement errors in the escapement estimates ($X$ variable) were shown (Jessop 1990a) to be minor (within ± 8%) and are believed to be less than measurement errors in the estimates of total return or numbers of virgin fish at age. Ordinary LS regression was thus assumed to be appropriate (Ricker 1975).

Plots of return on annual escapement indicated substantial scatter in the data and several possibly anomalous points for each species throughout the time series. Non-homogeneity of residual variances in OLS regression was addressed by logarithmic transformation of both variables. Least squares regression analysis is very sensitive to atypical values in the dependent and/or independent variable which makes it difficult to identify outliers in a residual analysis (Rousseeuw and Leroy 1987; Chen et al. 1994). The robust regression method, least median squares (LMS), is insensitive to atypical variable values and outliers can easily be identified by residual analysis using procedures given in Rousseeuw and Leroy (1987) and Chen et al. (1994). Basically, the LMS procedure is used to identify outliers and a re-weighted least squares regression (RLS; an LS estimator with a weight of 0 for outliers and 1 for normal data points, i.e., outliers are excluded) is used to estimate parameter variation which is comparable to that estimated by LS regression. Autocorrelation in the variables was statistically highly significant ($P < 0.01$) in most regressions according to the Durbin-Watson D statistic and the first order autocorrelation $r$-values (Wilkinson et al. 1996). Such autocorrelation underestimates the variance of the error terms and standard deviation of the regression coefficients, overestimates the significance of regression coefficients and underestimates the width of confidence intervals (Neter et al. 1996). The standard errors, 95% confidence intervals (95% CI), and significance of the regression coefficients were estimated by randomization (5000 replications) (Manly 1997).

The highest values of the adjusted coefficient of determination ($r^2_{adj}$) were used to select the best relations where each regressor was autocorrelated (Helland 1987) which also permits comparison of $r^2$ for linear (untransformed) and nonlinear (transformed) regression models (Kvålseth 1985). Statistical significance was accepted at $P \leq 0.05$.

Possible explanations for a relationship between the returns and annual escapements of both species might include temporal variability in biological factors that might be linked to marine environmental conditions. The time series of sea surface temperatures for Halifax Harbour and for the Prince 5 Station in the lower Bay of Fundy are unsatisfactory indicators of conditions on the Scotian Shelf, with correlations of the annual anomalies (deviations from the long-term mean) explaining less than 32% of the annual variability over the 1947-2000 period (B. Petrie, Department of Fisheries and Oceans, personal communication). The most suitable index of marine environmental conditions off the Scotian Shelf where many alewives and blueback herring overwinter (Stone and Jessop 1992) may be the Emerald Bank time series (Petrie and Drinkwater 1993). Gaspereau catch and abundance data was examined by correlation analysis for lagged relations with the smoothed (5-year) annual water temperature anomaly at 30, 100, and 250 m from the Emerald Basin on the Scotian Shelf (data from K. Drinkwater, Department of Fisheries and Oceans, Dartmouth, N.S.). The gaspereau data included: (1) the annual total harvest of gaspereau from the Saint John River (1952-1998), (2) alewife and blueback herring year-class size at age 3, and (3) the ratio of year-class size at age 3 to the spawning escapement producing the year-class, for both alewives and blueback herring. If the ratio of year-class size to spawning escapement is high, it is hypothesized that survival at sea (and in freshwater) was higher than average and vice versa. The data were differenced to remove temporal trend and autocorrelation as indicated by autocorrelation analysis (Wilkinson et al. 1996). Cross-correlation analysis indicated that lagging was not required. The correlation coefficient $r$, 95% confidence intervals and statistical significance were estimated by randomization (5,000 replications)

because of the non-normal distribution of variables and the presence of outliers. Possible factors influencing the freshwater life phase were also considered.

Temporal trends were examined, by species, sex and age, in the mean length, weight and age at first maturation or spawning (virgin) and in the proportion of virgin spawners occurring at each age. The mean age-at-first-spawning is an index of the proportion of virgin fish first spawning at each age (typically ages 3-6). Trends in partial (platoon) recruitment were examined for each species by applying the sample age composition of virgin fish to the estimated run abundance and then estimating the proportion at each age for a given year-class. Temporal relations between the exploitation rate of each species and the proportion of previous spawners (PPS) in the stock were also examined.

## Results

### Stock-Recruitment Relation

Annual total run sizes of alewives and blueback herring to the Mactaquac Dam have been highly variable since 1968 (Figure 3). A 10-year cycle is evident in the combined total run of alewives and blueback herring, with peaks in 1978, 1988 and 1998. Autocorrelation among the time series of spawning escapements and returns was significant in most relations; consequently, most relations use differenced data. Returns in years *i*+4 and *i*+5 and year-class size at age 3 of alewives and blueback herring were not significantly related to spawning escapement in year *i* using OLS linear regression (Table 1; Figures 4, 6). That is, the OLS regression slopes were not significant but the intercepts were. Returns of alewives 4 and 5 years after a given spawning were essentially constant (no significant slope) at about 1.4-1.8 million fish over a range of escapements from less than 100,000 fish to 2.1 million fish. Returns of blueback herring 5 years after spawning were also essentially constant but 4 years after spawning returns increased significantly with increasing escapement. There was high variability at a given escapement, perhaps more so for blueback herring than for alewives. However, total returns consist of varying proportions of virgin and previous spawners and are less appropriate than year-class size for examining stock-recruitment relations. Thus, at alewife spawning escapements of 500,000-1,000,000 fish, the estimated year-class sizes at age 3 have ranged from 500,000-2,000,000 fish while blueback herring escapements of 200,000-300,000 fish produced year-class sizes at age 3 ranging from 100,000-2,500,000 fish. Examination of the high variability in annual return for a given escapement indicated the presence of outliers in the alewife and blueback herring data. OLS regression of the untransformed data is highly biased by the presence of outliers.

Annual returns of alewives declared to be outliers by LMS regression differed only slightly between returns in year *i*+4 and year *i*+5 and year-class returns at age 3 (Table 1; Figure 4). The *i*+4 alewife returns in years 1972-74, 1976, and 1983-1985 were determined by LMS regression to be outliers, resulting in an RLS regression with a non-significant slope ($P = 0.69$), significant intercept ($P < 0.001$) and poor fit ($r^2_{adj} = 0.00$). The *i*+5 alewife returns in the years 1970-1971, 1975 and 1983 were determined to be outliers, resulting in an RLS regression with a non-significant slope ($P = 0.56$), significant intercept ($P < 0.001$) and poor fit ($r^2_{adj} = 0.00$). Regression intercept values were similar at 1,090,000 fish for the *i*+4 alewife return and 1,185,000 fish for the *i*+5 return. Alewife year-class returns at age 3 for 1972, 1973, 1983, 1988, 1993 and 1994 were determined to be outliers, resulting in an RLS regression with a significant slope ($P = 0.008$) and intercept ($P < 0.001$) and moderate fit ($r^2_{adj} = 0.28$).

Residual analysis of the OLS regressions indicated that a logarithmic transformation of the variables was appropriate for both alewife and blueback herring to correct heteroscedastic variance. After transformation, all stock-recruitment regressions were significant except for alewife returns in years *i*+4 and *i*+5 (Table 1; Figures 5, 7). Logarithmic transformation largely eliminated the problem of outliers except for the years 1982 and 1983 for blueback herring returns at year *i*+5 and 1983 for returns at year *i*+4 and for the year 1974 for alewife returns at year *i*+4.

No significant correlations were found between the annual total catch of gaspereau from the Saint John River or the year-class size at age 3 or the ratio of year-class size to the spawning escapement that produced it and the water temperatures at various depths in the Emerald Basin on the Scotian Shelf (Table 2; Figure 8).

**Effects of Exploitation**

The proportion of fish of a given age, typically ages 3-6, returning as virgin spawners has varied annually for both alewives and blueback herring (Figure 9A), reflecting variability in the age at first recruitment (partial recruitment). The annual mean ages at first spawning are higher for females than for males for both alewives and blueback herring. Mean ages at first spawning (LOWESS-smoothed) declined from about 4.9 to 4.3 years (12%) for female alewives and 4.8 to 4.2 years (13%) for male alewives (Figure 9B). Blueback herring showed smaller declines in mean age at first spawning than did alewives, from 4.1 to 3.9 years (5%) for females and from 3.9 to 3.6 years (8%) for males. The mean age at first spawning declined less for blueback herring than for alewives even though the median annual exploitation rate was higher for blueback herring (Figure 10).

Since the late 1970s, the annual proportion of alewives first spawning at ages 3 and 4 increased while the proportion maturing at ages 5 and 6 decreased (Figure 10). For blueback herring, the proportion spawning first at age 3 increased slightly, the proportion at age 4 remained essentially constant, although with high variability (range 5-73%), and the proportions at ages 5 and 6 declined. The period prior to about 1977 should be discounted because the stocks of both species were undergoing rapid growth in abundance and exploitation began only in 1974.

Annual partial recruitments (the proportions of a given year-class returning as virgin fish of a specific age, i.e., ages 3-6) also changed temporally. Thus, for the 1970 to 1974 year-classes, the partial recruitment of alewives at age 4 averaged 22.6% (range 8.5-44.0%), changing to an average of 66.2% (range 41.3-79.2%) for the 1990-1994 year-classes. Alewife partial recruitment at age 5 for the 1970-1974 year-classes averaged 61.7% (range 45.0-82.5%), changing to an average of 30.0% (range 17.8-56.2%) for the 1990-1994 year-classes. For blueback herring, temporal trends in partial recruitment occurred at ages-3 and 5 with age 4 showing little trend but high variability (range 5.6-91.6%). Blueback herring partial recruitment at age 3 increased from 6.5% (range 1.0-14.2%) for the 1970-1974 year-classes to 23.1% (range 8.3-41.8%) for the 1990-1994 year-classes while correspondingly decreasing at age-5 from 34.1% (range 26.0-41.2%) to 11.6% (range 7.0-22.6%).

Annual mean lengths and weights at first spawning for virgin ages 3-5 have declined significantly from their highs around 1980, for ages 4 and 5 and for both sexes of alewife and blueback herring (Figures 11, 12). The decline is evident from the non-overlap of the 95% CI and was confirmed by linear regression. No trend is evident for age-3 fish due to the shorter time span covered and greater variability in size at age resulting from small sample sizes.

Since 1974, exploitation rates for alewives and blueback herring have varied widely between the species and among years, ranging from 0.12-0.90 (median = 0.43) for alewives and 0.32-0.99 (median = 0.79) for blueback herring, excluding 1986 when no fishery occurred (Figures 3, 13). The cumulative effects of annual exploitation on both alewives and blueback herring has been to reduce the proportion of previous spawners (PPS) in the run from about 0.8 when unexploited to 0.3 over a period of 26 years (Figure 13). Since 1990, exploitation rates have typically been less than 0.5 for alewives and greater than 0.5 for blueback herring. Over this 11 year period, exploitation rates for alewives averaged 0.33 (range 0.12-0.51) and produced a PPS in the stock averaging 0.31 (range 0.16-0.51). For blueback herring, a mean exploitation rate of 0.68 (range 0.40-0.86) has resulted in a PPS of 0.27 (range 0.05-0.44).

## Discussion

### Stock-Recruitment Relation

Relations between spawning escapement, juvenile production, and adult return are complex and differ between alewives and blueback herring (Jessop 1990a, 1994b). The range of spawning stock sizes and the high variability in recruitment for a given spawning stock size substantially influences the detection of a stock-recruitment relation (Hilborn and Walters 1992). Although the total return of alewives and blueback herring 4 and 5 years after spawning, as estimated by OLS regression, was essentially constant, the high variability about any estimate makes for poor predictive use. The detection and removal of outliers from the stock-recruitment relation simply reduced the value of the regression intercept and resulted in a significant slope only for blueback herring returning in year *i*+4. Year-class size was a more useful variable in a stock-recruitment relation. After outlier removal, stock-recruitment relations were significant for alewives and blueback herring when based on year-class. Logarithmic transformation to reduce the effects of high variability also resulted in significant stock-recruitment relations for both alewives and blueback herring, particularly when year-class was used as the recruitment measure.

The nature of the stock-recruitment relation has evidently changed over time. Recruitment values that drove the relation until the early 1980s (Jessop 1990a) can now be regarded as outliers that increase the variability of the longer-term relation. The assumption of time-invariant relations between stock size and recruitment is often unmet, and when unmet, may require appropriate changes in stock size and exploitation rate targets (Walters 1987). The stock-recruitment relation most appropriate for current use may be the one that excludes outliers that originated under conditions that no longer apply.

The cause(s) of unusually high or low recruitment from a given escapement is uncertain but likely environmentally mediated. High alewife returns in the early-mid 1970s may have resulted from high productivity in the newly developed headpond, high recruit per spawner values at low spawner abundance, and "surplus" returns resulting from incomplete passage of fish at the dam during years of high return in the 1970s (Jessop 1990a). Low alewife returns in the early 1990s from high escapements in the late 1980s may result from increasing density-dependence due to a decline in headpond productivity as it ages and/or low marine survival. Seasonal discharge from the Mactaquac Dam can affect survival of juveniles inhabiting the headpond (Jessop 1990a, 1994b) but relations between adult returns to the dam and seasonal discharge are ambiguous. The mortality of juvenile and adult gaspereau during downstream passage through the turbines is unknown but assumed, likely erroneously, to be constant over time. Installation of the final two (of six) turbines at the Mactaquac Dam in 1979 and 1980 does not coincide with the unusually low returns during the early 1990s for the high alewife escapements of the late 1980s. The presence of a substantial proportion of previous spawners when exploitation rates are low suggests that turbine-induced mortality of juvenile and adult gaspereau is not a serious problem although it undoubtedly shifts the stock-recruitment relation downwards.

Raising of the headpond level by 0.9 m in 1984 was expected to increase headpond productivity for several years (Anon. 1980), temporarily reinvigorating headpond productivity, which typically decreases with ageing over a period of perhaps 10 years (Kimmel and Groeger 1986). The Mactaquac Dam headpond was expected to decrease in productivity following improvements in water quality resulting from the 1970s program of pollution abatement in the Saint John River (Watt and Duerden 1974). Consequently, headpond productivity currently is expected to be lower than during the 1970s, resulting in lower production of primarily planktivorous juvenile gaspereau.

The absence of significant correlation between measures of stock abundance and water temperatures at a site on the Scotian Shelf is insufficient evidence to conclude that oceanic conditions do not have a major effect on the marine survival and abundance of gaspereau. Gaspereau may occupy depths of up to 350 m on the Scotian Shelf (Stone and Jessop 1992). The appropriate environmental indicators have perhaps not been found and may not yet exist because of limitations in the nature of existing environmental data (Drinkwater et al. 1998; Drinkwater 2000).

**Effects of Exploitation**

Fishing exploitation can be described as a "massive, uncontrolled experiment in evolutionary selection" (Rijnsdorp 1993; Stokes and Law 2000) and, as such, is no different from other forms of predator-induced mortality that influence fish survival. Moderate annual exploitation for alewives and high exploitation rates for blueback herring have reduced the mean age, length and weight at first spawning of alewives and blueback herring returning to the Mactaquac Dam. These phenotypic characteristics are probably genetically mediated to some degree since exploitation rates substantially higher than natural mortality rates can be expected to have a measurable selection pressure (Trippel 1995; Stokes and Law 2000). However, the role of genetic and non-genetic (environmental) factors in the production of phenotypic change is a matter of debate (Conover 2000; Stokes and Law 2000).

High exploitation reduced the proportion of previous spawners in the stock. Blueback herring seemed more resistant or resilient in their response to exploitation rate than did alewives given that higher exploitation of the blueback was required to attain a PPS similar to that for alewives. The estimated production of blueback herring recruits from the spawning escapement to the Mactaquac Lake may, in recent years, be artificially high. An influx of migrant blueback herring from potential spawning areas in the backwater at the base of the dam and in the inter-island area 5-15 km downstream of the dam (Loesch 1987; Jessop 1990a) could inflate the apparent exploitation rate and buffer the PPS value. Fishery exploitation rates may also be biased high in their effect on the PPS by the degree of mortality occurring post-spawning (common to all stocks) and during downstream passage through the turbines at the Mactaquac Dam. The adult mortality rate during downstream passage is unknown but is believed to be low given the rapid increase in stock size and proportion of previous spawners prior to establishment of the fishery. A reduced mean length and weight at maturity and a decrease in the proportion of previous spawning (larger) fish due to high exploitation reduces the reproductive potential of the stock for a given spawning escapement consequent to decreased fecundity and smaller egg size for smaller spawners (Jessop 1993; Trippel 1995).

Exploitation rates are difficult to accurately estimate for many stocks yet they have a major effect on the rate of survival to reproduction and the age at maturity or first reproduction, which are fundamental to population growth and viability (Hutchings 2000). One measure of the cumulative effect of exploitation over time and thus a measure of stock health is the proportion of previous spawners in the stock, which declines with increasing exploitation and is readily measured. Unexploited or lightly exploited alewife and blueback herring stocks have a high PPS, consisting of perhaps 6-8 year-classes and ages from 5-12 (Jessop et al. 1982). Average exploitation rates of 0.3 for alewives and 0.7 for blueback herring from the Mactaquac Lake stock appear suitable to maintain a relatively stable return of 1-2 million alewives and 1-2 million blueback herring. At these exploitation rates, the PPS stabilized around 0.3, with a range of variation (0.4) slightly larger than the mean. Consequently, a PPS in the Mactaquac gaspereau stock of 0.3 indicates a sustainable exploitation rate, although probably not an optimal exploitation rate. A PPS reference point scale might be: >0.6 indicates a lightly or unexploited stock, 0.4 indicates a moderately exploited stock, 0.3 indicates a heavily but sustainably exploited stock, and <0.2 indicates an unacceptably high exploitation rate and a need to immediately reduce exploitation. Attainment of a given level of PPS could be evaluated by a running mean of 3-5 years. The degree to which such a scale might apply to other stocks remains to be determined. If generally applicable, such a scale could offer a useful method, in conjunction with other biological reference points, to assess stock status.

**Management Considerations**

The existing management plan for the Mactaquac Lake gaspereau stock requires an annual spawning escapement of 800,000 alewives and 200,000 blueback herring. The fixed escapement plan implemented during the 1990s has, to date, proved successful in maintaining a substantial return of gaspereau that supports a commercial harvest, does not overwhelm the capacity of the fish-lift, and does not unduly interfere with the collection of Atlantic salmon at the fish-lift. A program of active stock management to achieve alewife escapements greater than 1,000,000 fish and blueback herring escapements greater than 400,000 fish is required to further elucidate the evolving nature of gaspereau stock-recruitment to Mactaquac Lake. Maintenance of the existing management plan

levels of escapement should maintain stock abundance sufficient to achieve current escapement targets and continue the existing fishery near current levels.

## Acknowledgements

I thank all those who have participated with me in the sample collection, processing and scale ageing, and other ways since this project began, particularly W. E. Anderson, H. A. Parker, H. H. Stone, D. Ingraham, L. Anderson, and R. Jones.

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**Table 1. Parameter values for least squares (OLS) and reweighted least squares (RLS) regressions and associated adjusted $r^2$ and $P$ values, of annual return and year-class (Y) on escapement (X) for alewives and blueback herring returning to the Mactaquac Dam, Saint John River, New Brunswick, 1968-2000. Variables were coded (÷ 1,000); $i$ = year of escapement.**

| Return | | Regression | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | Year | *N* | Intercept | 95% CI | *P* | Slope | 95% CI | *P* | $r^2$ | Comment |
| | | | | | **Alewife** | | | | | |
| Total | *i*+5 | 28 | 1398.4 | 808.7 - 1790.7 | <0.001 | 0.184 | -0.301 – 1.420 | 0.57 | 0.00 | OLS |
| | *i*+5 | 22 | 1185.3 | 832.4 – 1490.6 | <0.001 | 0.014 | -0.242 – 0.640 | 0.96 | 0.00 | RLS – outlier years 70,71,72,73,75,83 |
| | *i*+5 | 28 | 2.8494 | 2.0576 – 3.3345 | <0.001 | 0.1051 | -0.0745 – 0.3939 | 0.29 | 0.01 | Log-log transform, OLS |
| Total | *i*+4 | 29 | 1415.0 | 996.8 – 1802.8 | <0.001 | 0.125 | -0.328 – 0.996 | 0.69 | 0.00 | OLS |
| | *i*+4 | 21 | 1090.8 | 901.4 – 1340.9 | <0.001 | 0.028 | -0.368 – 0.226 | 0.87 | 0.00 | RLS – outlier years 71,72,73,74,76,83,84,85 |
| | *i*+4 | 29 | 2.9602 | 2.6213 – 3.4062 | <0.001 | 0.0608 | -0.112 – 0.200 | 0.55 | 0.00 | Log-log transform, CLS |
| Year-class | *i* | 27 | 745.6 | 377.1 – 1030.7 | <0.001 | 0.325 | -0.044 – 1.043 | 0.14 | 0.05 | OLS |
| | *i* | 21 | 487.2 | 300.8 – 727.7 | <0.001 | 0.502 | 0.090 – 0.771 | 0.008 | 0.28 | RLS – outlier years 72,73,83,88,93,94 |
| | *i* | 27 | 2.3004 | 1.6553 – 2.644 | <0.001 | 0.2306 | 0.0947 – 0.4674 | 0.043 | 0.12 | Log-log transform, OLS |
| | | | | | **Blueback herring** | | | | | |
| Total | *i*+5 | 27 | 1196.2 | 475.1 – 1892.1 | <0.005 | 0.930 | -1.748 – 5.252 | 0.49 | 0.00 | OLS |
| | *i*+5 | 23 | 817.3 | 533.7 – 1233.5 | <0.001 | 0.820 | -1.267 – 2.495 | 0.22 | 0.03 | RLS – outlier years 80,82,83,84 |
| | *i*+5 | 27 | 2.3361 | 1.9176 – 3.2179 | <0.001 | 0.3222 | -0.0650 – 0.5317 | 0.017 | 0.17 | Log-log transform, OLS |
| Total | *i*+4 | 28 | 954.5 | 341.5 – 1559.0 | <0.005 | 1.9438 | 0.154 – 6.30 | 0.17 | 0.03 | OLS |
| | *i*+4 | 24 | 620.3 | 393.0 – 964.4 | <0.001 | 1.6714 | 0.079 – 2.746 | 0.002 | 0.25 | RLS – outlier years 81,83,84,85 |
| | *i*+4 | 28 | 2.0402 | 1.704 – 2.594 | <0.001 | 0.4470 | 0.198 – 0.620 | <0.001 | 0.32 | Log-log transform, OLS |
| Year-class | *i* | 27 | 519.1 | 79.5 – 908.2 | <0.05 | 1.149 | -0.105 – 4.098 | 0.25 | 0.01 | OLS |
| | *i* | 19 | 95.44 | -5.7 – 284.8 | >0.20 | 1.1363 | 0.133 – 1.518 | 0.002 | 0.49 | RLS – outlier years 82,83,84,85,88,89,90,93 |
| | *i* | 27 | 1.3273 | 0.6864 – 2.4134 | <0.005 | 0.6011 | 0.1293 – 0.8907 | 0.004 | 0.25 | Log-log transform, OLS |

Table 2. Correlations, with 95% confidence interval (CI) and significance (*P*), between (1) annual total catch of gaspereau from the Saint John River, (2) the ratio between year-class size at age 3 and the spawning escapement producing it and (3) the year-class size at age 3 of alewives and blueback herring from the Mactaquac Dam and the annual mean, smoothed (5 year), water temperatures (°C) from the Emerald Basin, Scotian Shelf, at several water depths.

| Biological data | Depth (m) | *N* | *r* | 95% CI | *P* |
|---|---|---|---|---|---|
| Saint John R. catch | 30 | 46 | 0.16 | -0.08 – 0.41 | 0.23 |
| (species combined) | 100 | 46 | -0.005 | -0.20 – 0.20 | 0.98 |
| | 250 | 46 | -0.04 | -0.29 - 0.19 | 0.83 |
| Mactaquac Dam | | | **Alewife** | | |
| Year-class/escapement | 30 | 26 | -0.05 | -0.47 – 0.50 | 0.54 |
| | 100 | 26 | -0.22 | -0.69 – 0.38 | 0.34 |
| | 250 | 26 | -0.36 | -0.72 – 0.27 | 0.12 |
| Year-class | 30 | 26 | -0.09 | -0.53 – 0.38 | 0.76 |
| | 100 | 26 | 0.04 | -0.37 – 0.48 | 0.93 |
| | 250 | 26 | 0.02 | -0.21 – 0.27 | 0.87 |
| | | | **Blueback herring** | | |
| Year-class/escapement | 30 | 26 | -0.06 | -0.46 – 0.34 | 0.83 |
| | 100 | 26 | -0.09 | -0.41 - 0.26 | 0.60 |
| | 250 | 26 | -0.25 | -0.55 – 0.05 | 0.11 |
| Year-class | 30 | 26 | -0.003 | -0.53 – 0.44 | 0.89 |
| | 100 | 26 | -0.02 | -0.23 – 0.46 | 0.40 |
| | 250 | 26 | -0.14 | -0.29 – 0.01 | 0.08 |

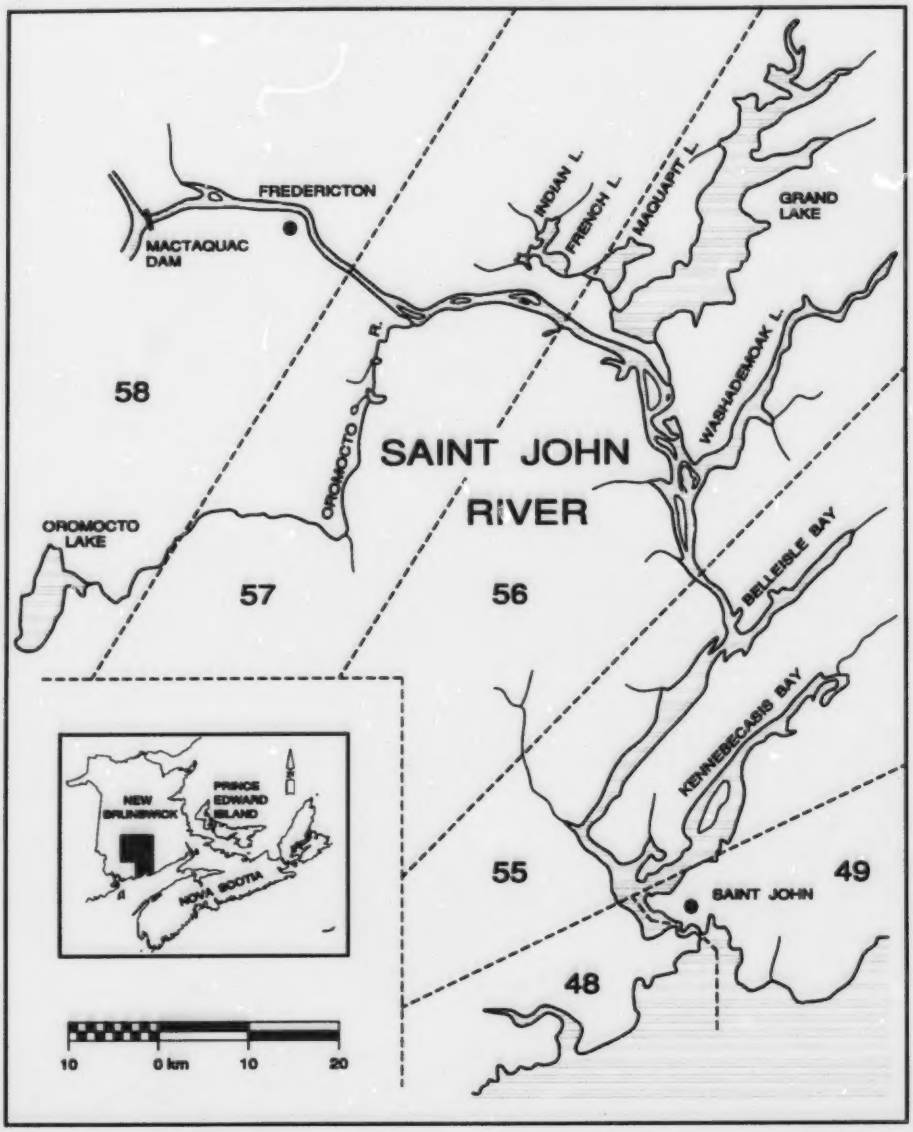


Figure 1. Map of the lower Saint John River, New Brunswick, with Fishery Statistical Districts numbered.

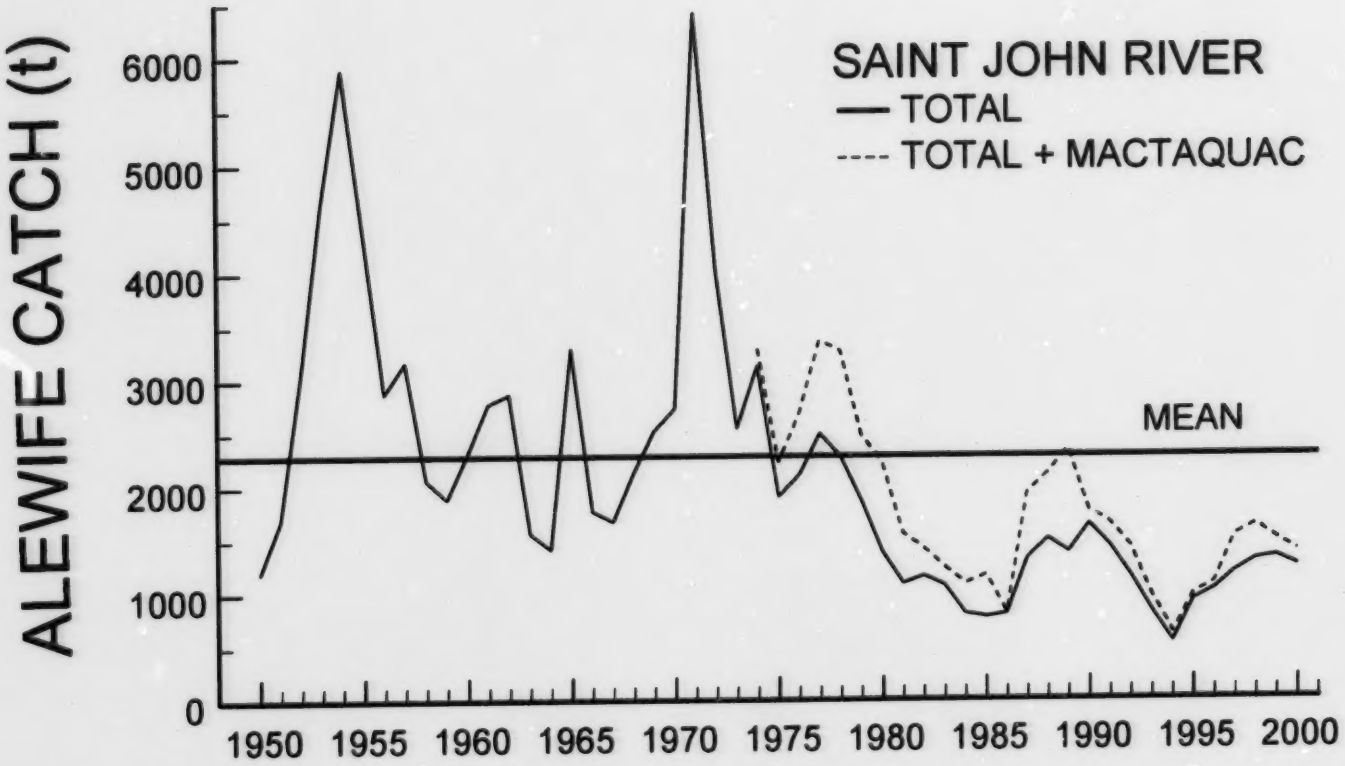


Figure 2. Annual reported catch (t) of alewife (alewives and blueback herring) from the Saint John River and at the Mactaquac Dam, New Brunswick, 1950-2000. The long-term mean catch is 2,284 t.

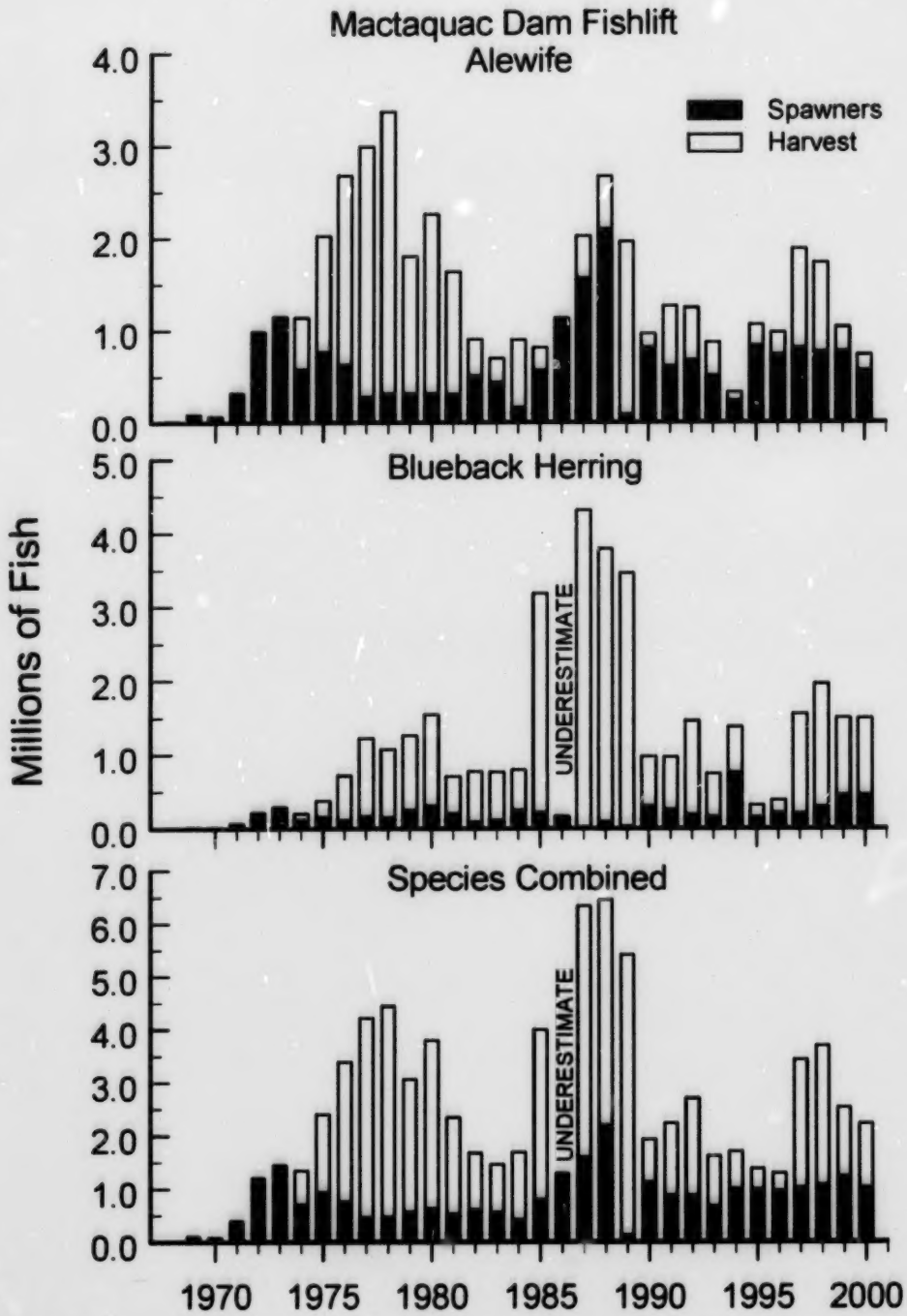


**Figure 3. Harvest, spawning escapement, and return (harvest + escapement) of alewives and blueback herring at the Mactaquac Dam, Saint John River, 1968-2000.**

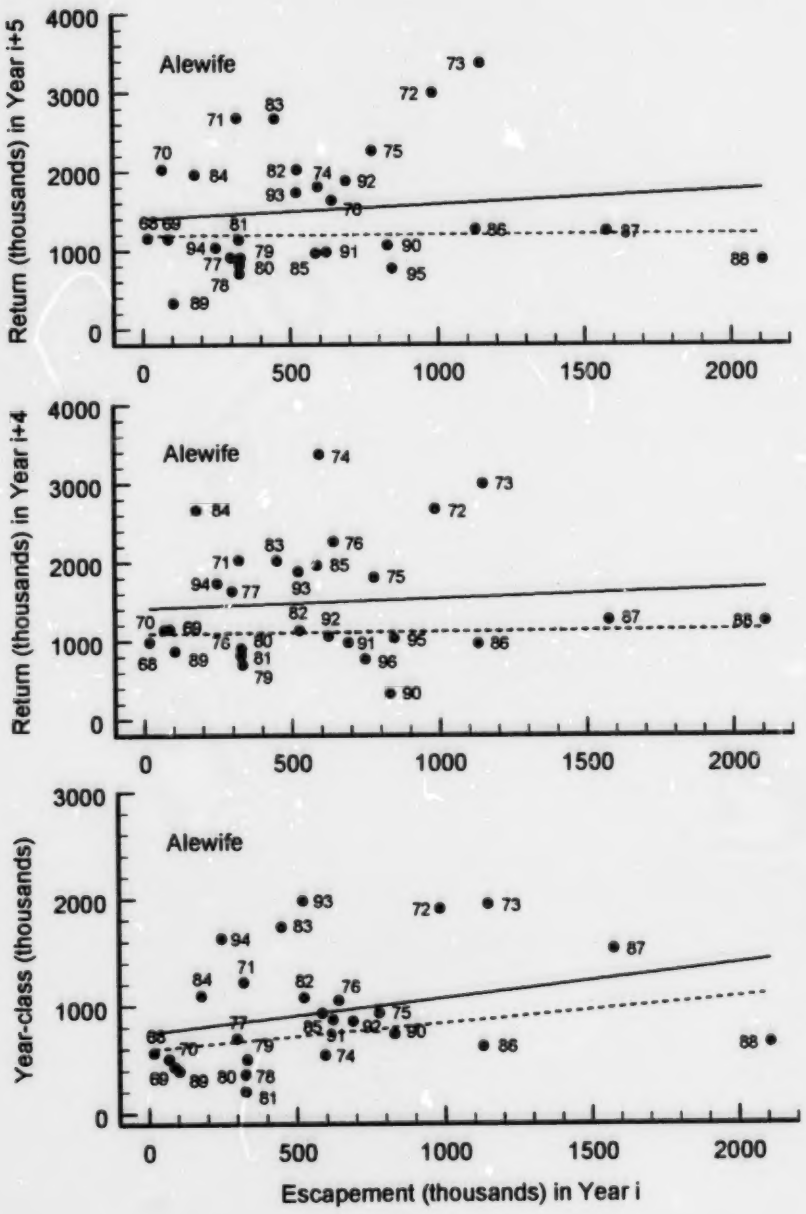


Figure 4. Regressions of returns (mature fish, all ages) in years *i*+4 and *i*+5 and year-class size at age 3 on spawning escapement to Mactaquac Lake in year *i* of alewives from the Mactaquac Dam, Saint John River. A solid line indicates regressions with all data; exclusion of outliers detected by least median of squares regression is indicated by a dashed line.

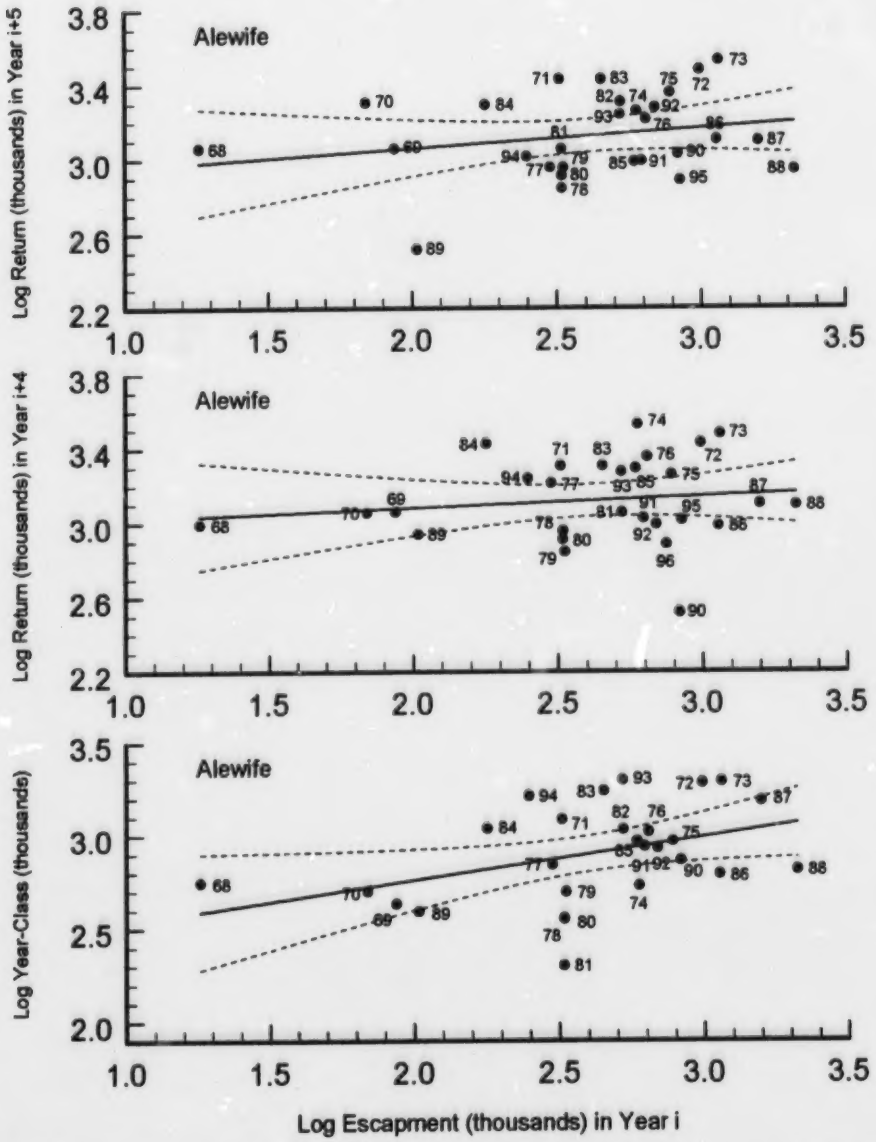


Figure 5. Regressions of logarithmically transformed (base 10) return (mature fish, all ages) in years *i*+4 and *i*+5 and year-class size at age 3 on spawning escapement to Mactaquac Lake in year *i* of alewives from the Mactaquac Dam, Saint John River. Dashed lines indicate 95% CI about the regression line.

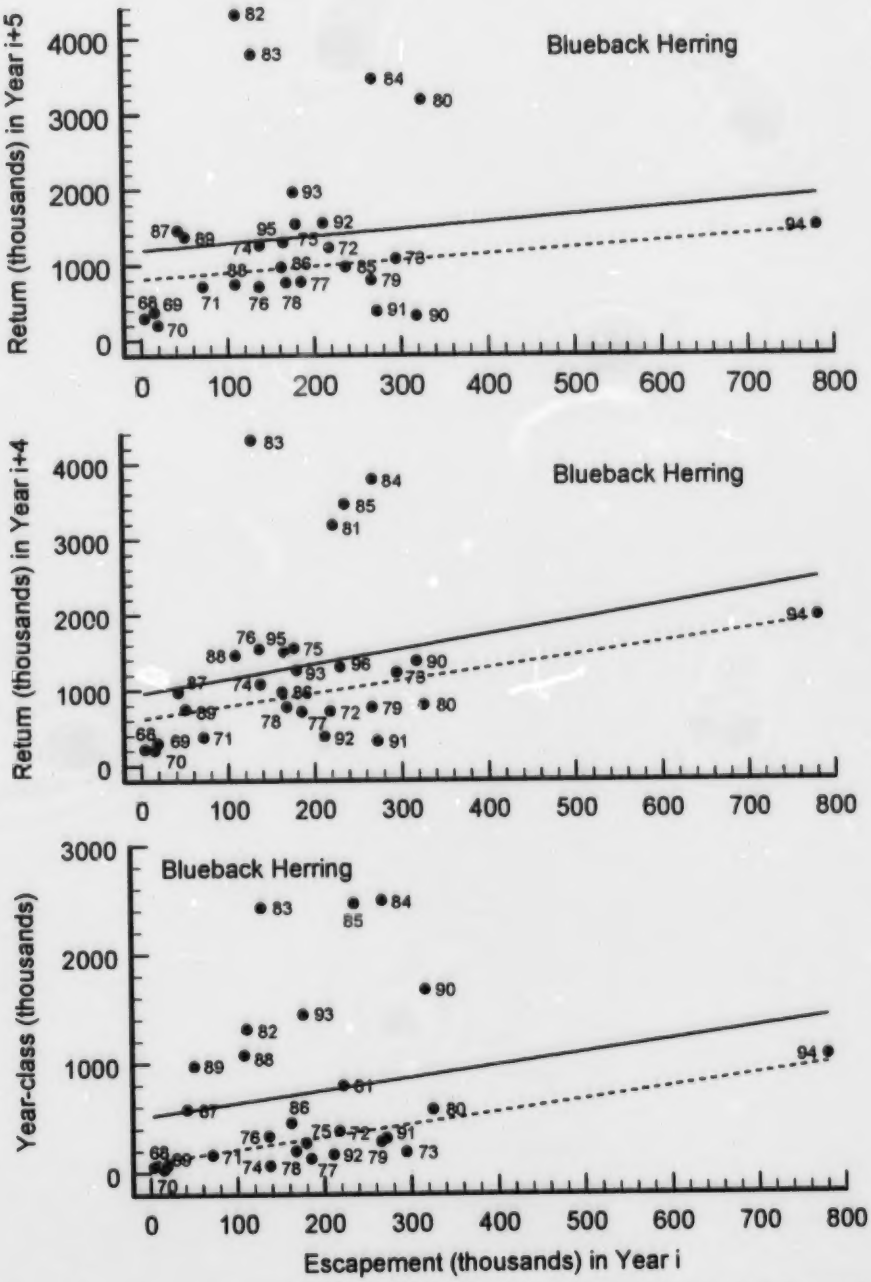


Figure 6. Regressions of return (mature fish, all ages) in years *i*+4 and *i*+5 and year-class size at age 3 on spawning escapement to Mactaquac Lake in year *i* of blueback herring from the Mactaquac Dam, Saint John River. A solid line indicates regressions with all data; exclusion of outliers detected by least median of squares regression is indicated by a dashed line.

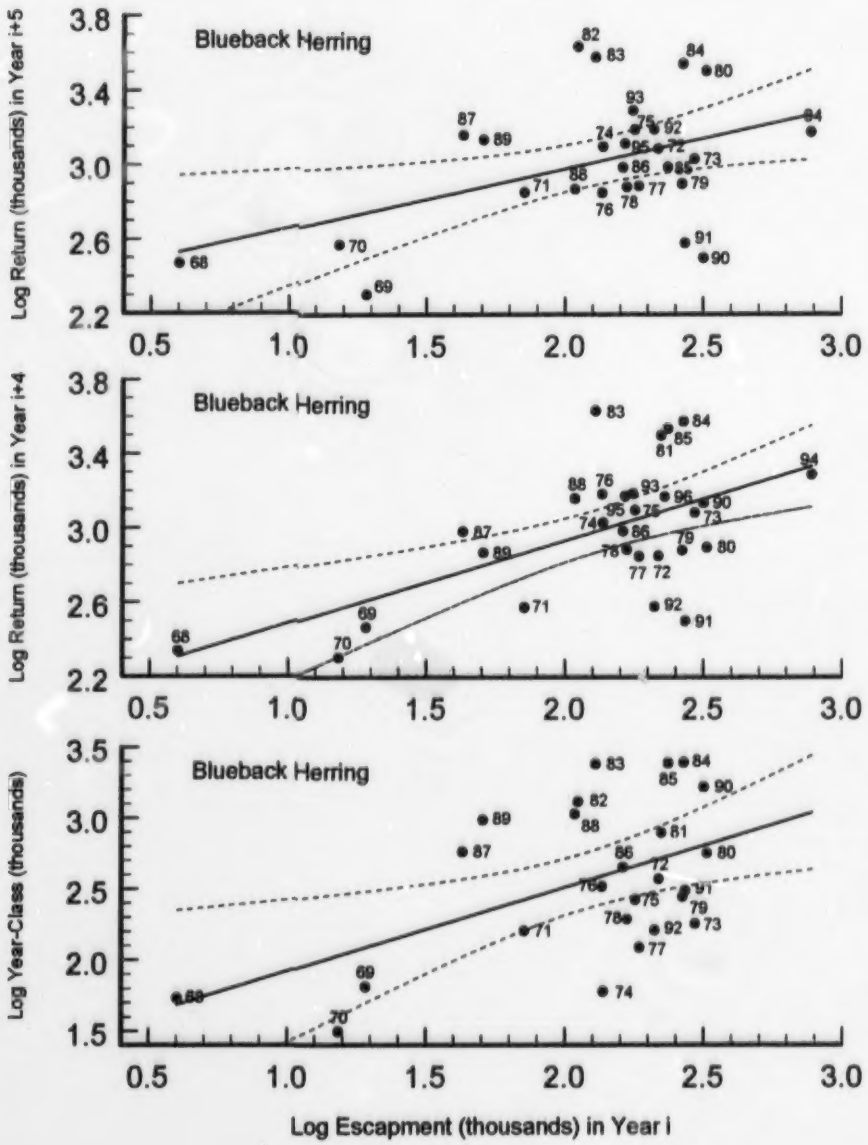


**Figure 7. Regressions of logarithmically transformed (base 10) return (mature fish, all ages) in years *i*+4 and *i*+5 and year-class size at age 3 on spawning escapement to Mactaquac Lake in year *i* of blueback herring from the Mactaquac Dam, Saint John River. Dashed lines indicate 95% CI about the regression line.**

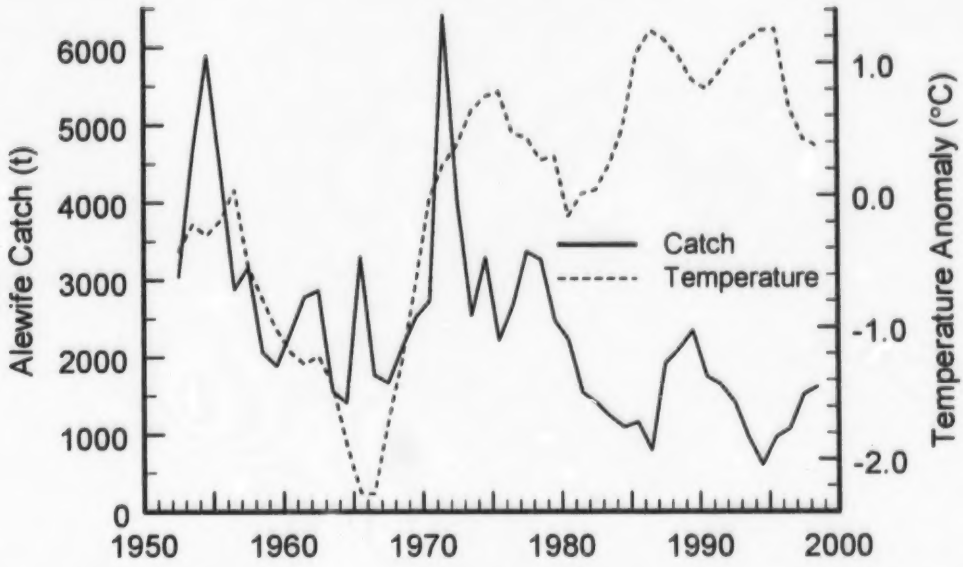


Figure 8. Annual catch (t) of gaspereau from the Saint John River, N. B. and water temperature anomaly from the smoothed (5 year) mean water temperatures at 250 m from the Emerald Basin, Scotian Shelf. The temporal anomaly patterns at 30 and 150 m were similar to that at 250 m.

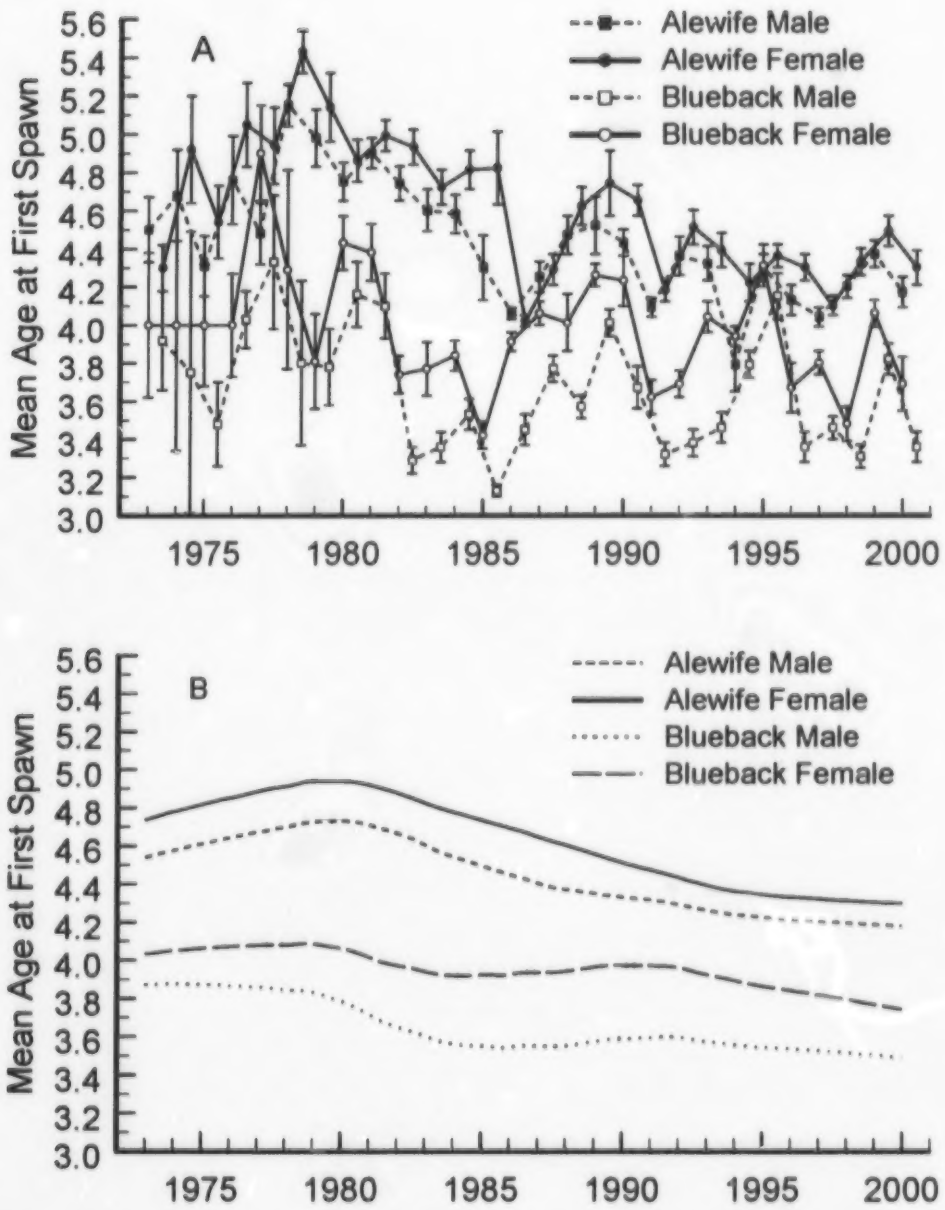


**Figure 9. Temporal variability in annual mean age at first spawning of virgin fish, with 95% CI (A), with temporal trend indicated by loess smoothed (span = 0.5) means (B), of alewife and blueback herring, by sex, from the Mactaquac Dam, Saint John River, 1973-2000.**

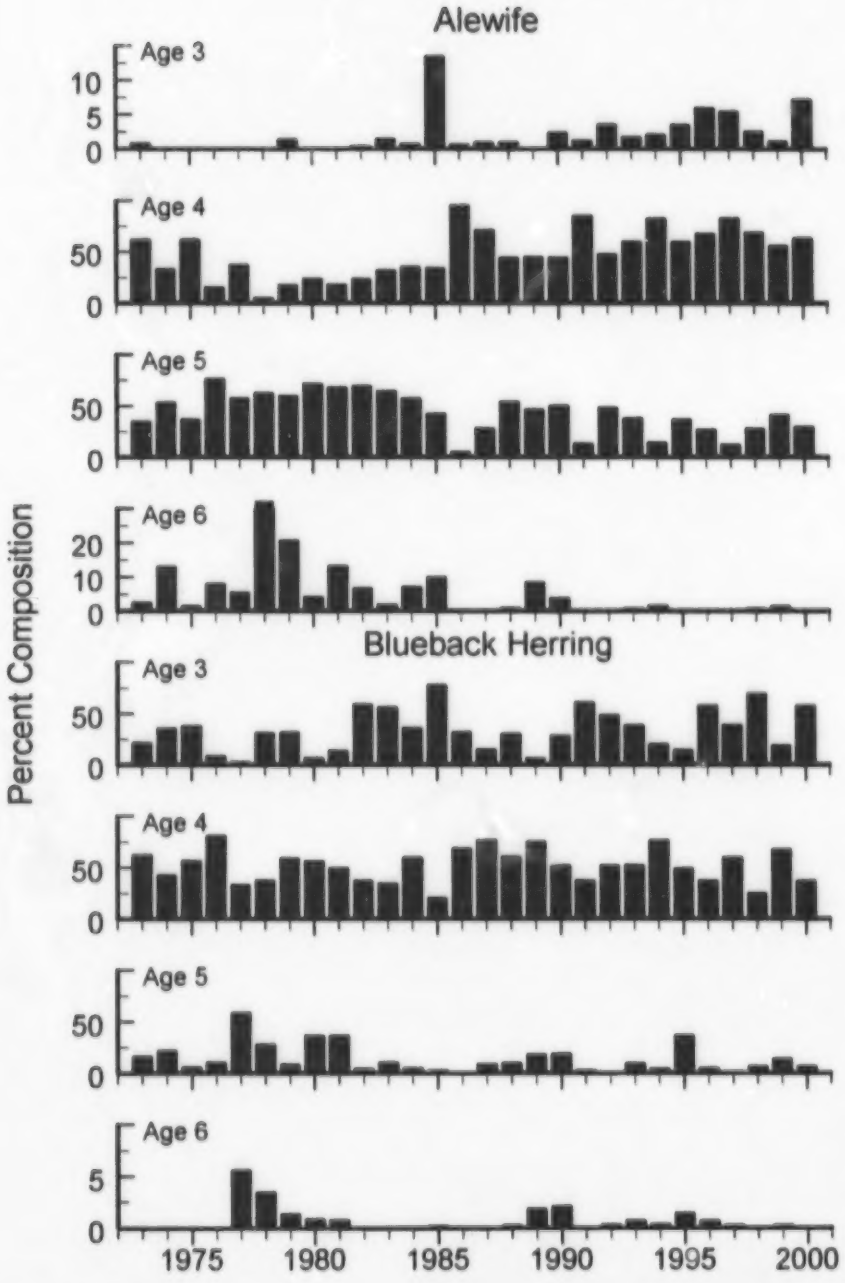


Figure 10. Temporal changes in the annual percent recruitment of virgin alewives and blueback herring (sexes combined), by age, from the Mactaquac Dam, Saint John River, 1973-2000.

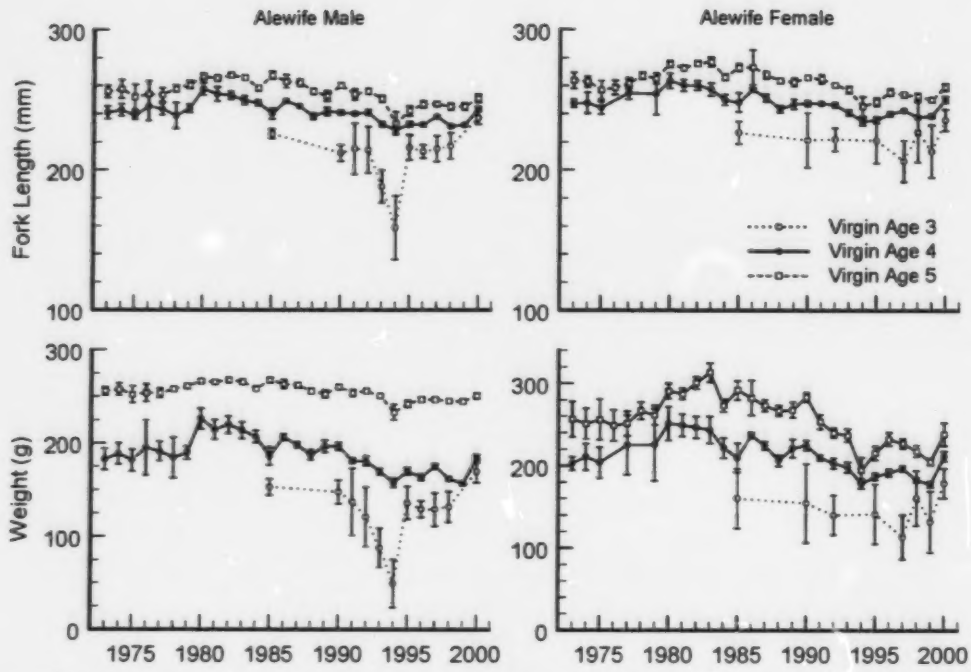


Figure 11. Temporal changes in annual mean length and weight at first spawning of virgin fish, with 95% CI, by age, for male and female alewives from the Mactaquac Dam, Saint John River, 1973-2000.

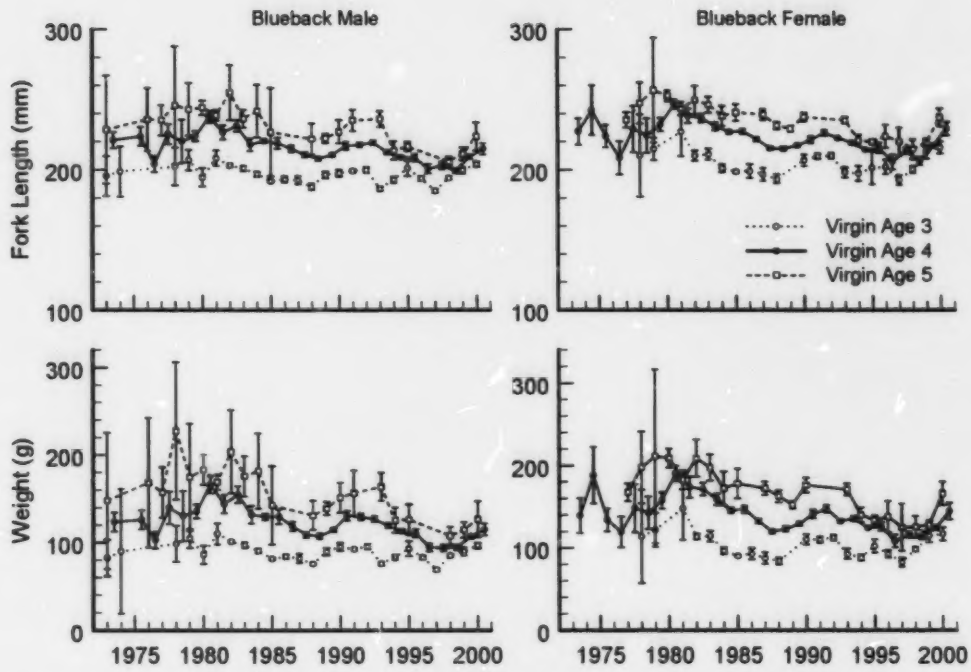


Figure 12. Temporal changes in annual mean length and weight at first spawning of virgin fish, with 95% CI, by age, for male and female blueback herring from the Mactaquac Dam, Saint John River, 1973-2000.

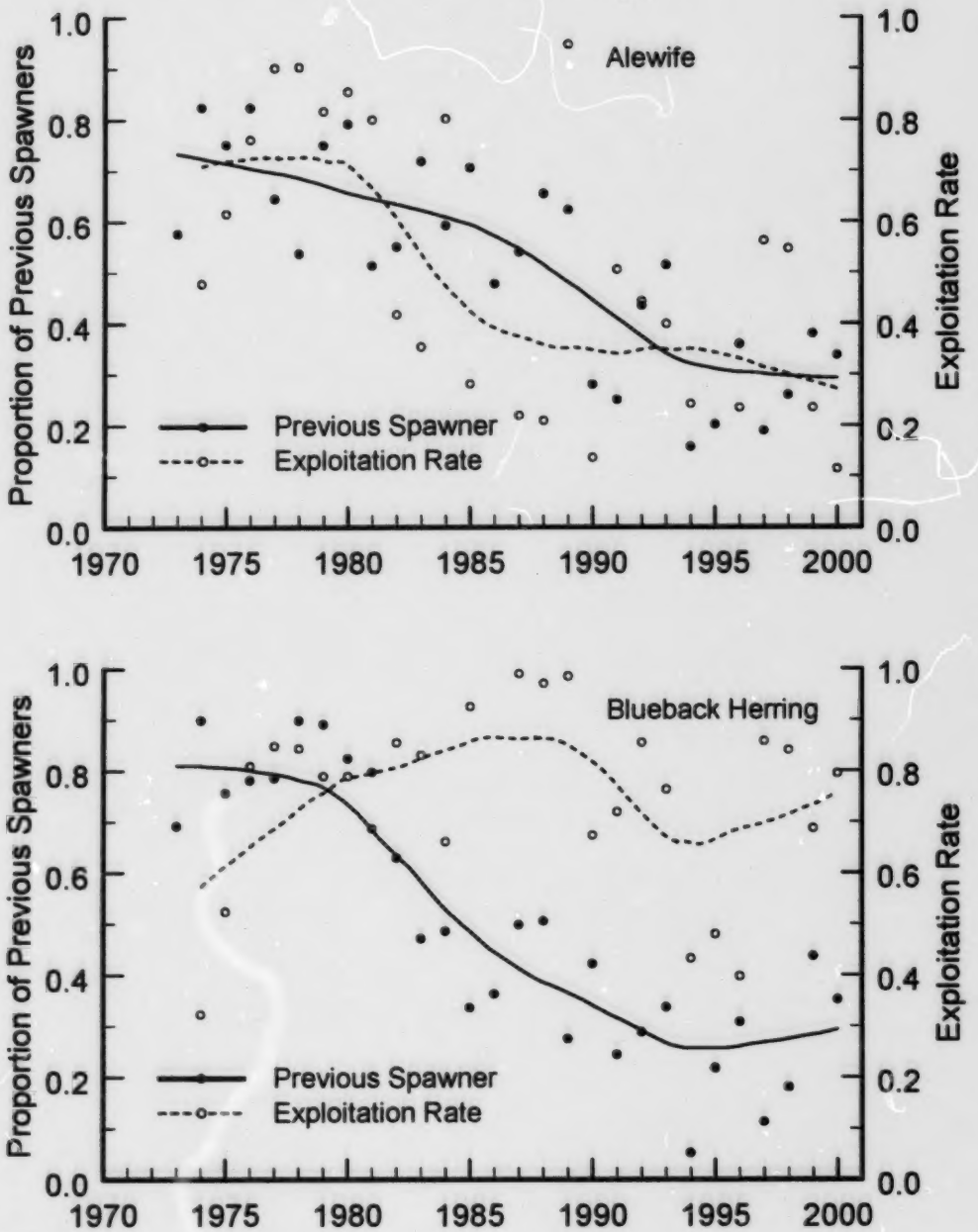


**Figure 13. Temporal change in the annual exploitation rate and proportion of previous spawners in the stock of alewives and blueback herring from the Mactaquac Dam, Saint John River, 1973-2000. The lines indicating trend were LOWESS smoothed (span = 0.5).**